

THE EFFECT OF VALVE OVERLAP
ON DETONATION LIMITED
ENGINE PERFORMANCE

by

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M. S. Degree

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James B. McRae

THESE ARE THE RESULTS OF THE RESEARCH
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AT BERKELEY

Cambridge, Massachusetts,
June 1, 1947.

Professor Joseph S. Newell,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Dear Sir:

A thesis entitled "THE EFFECT OF VALVE OVERLAP
ON DETONATION-LIMITED ENGINE PERFORMANCE" is herewith sub-
mitted in partial fulfillment of the requirements for the
degree of Master of Science in Aeronautical Engineering.

Respectfully,

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The authors wish to express their appreciation to the entire staff of Sloan Laboratories, M.I.T., for their aid in making this thesis possible, and in particular to Professor A. R. Rogowski, Professor W. D. Leary and Mr. J. C. Livengood for their indispensable suggestions and guidance.

CONFIDENTIAL

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INTRODUCTION

The fact that detonation, or knocking, in an internal combustion engine is a function of many related and unrelated variables has caused considerable difficulty in the field of detonation research and engine design. To date, the practice has been to study the effect of these variables one at a time, endeavoring to hold all other variables constant. The purpose of this investigation is to hold all variables constant except the valve overlap and to thereby determine the detonation-limited characteristics of this variable alone.

Four different cam shafts, each with a different valve overlap, have been used in the investigation. The timing diagrams for these shafts are shown in Figure 1. In addition, the complete experiment has been conducted using two different types of fuel: (a) 80 octane automotive, and (b) di-iso-butylene.

The fact that detection of the engine is a function of many related variables has caused considerable difficulty in the field of detection research and engine design. The practice has been to study the effect of each variable one at a time, endeavoring to hold all other variables constant. The purpose of this investigation is to hold all variables constant except the valve overlap and to thereby determine the detection-limited characteristics of this variable alone.

Four different cam shafts, each with a different valve overlap, have been used in the investigation. The timing diagrams for these shafts are shown in Figure 1. In addition, the complete experiment has been conducted using two different types of fuel (a) 80 grade motor oil, and (b) diesel-oil.

SUMMARY

A series of tests have been conducted on a C.F.R. engine with camshafts whose valve overlap varied from 6° to 120° . In all cases the engine was operated at detonation limited inlet pressure. The tests were performed using two fuels: (a) 80-octane, and (b) di-iso-butylene.

The primary object of the tests was to determine the effect of varying valve overlaps on the detonation limited performance of the engine, and secondarily, to investigate the qualitative effect of residual gas on the fuel characteristics.

In the case of 80-octane, it was found that large overlaps permit the engine to develop greater power at high speed and that residual gas acts as an inhibitor.

In the case of di-iso-butylene, it was found that higher overlaps permit the development of higher power when running at low speeds and that overlap has relatively little effect on the power output at high speed. At the higher speeds the engine detonated at lower critical pressure, as previously discovered by other investigators, but no conclusion can be drawn as to the effect of residual gas on this reversal since, in these tests, this variable could not be isolated.

PLATE II

A series of tests have been conducted on the engine with compression ratios varying from 12 to 15. In all cases the engine was operated at constant limited inlet pressure. The tests were performed using two fuels: (a) 80-octane, and (b) 81-octane.

The primary object of the tests was to determine the effect of varying valve overlap on the detonation limited performance of the engine, and secondarily, to investigate the qualitative effect of residual gas on the fuel conversion.

In the case of 80-octane, it was found that large overlap permits the engine to develop greater power at high speed and that residual gas acts as an inhibitor. In the case of 81-octane, it was found that higher overlap permits the development of higher power when running at low speeds and that overlap has relatively little effect on the power output at high speed. At the higher speeds the engine detonated at lower critical pressures, as previously discovered by other investigators, but no conclusion can be drawn as to the effect of residual gas on this reversal since, in these tests, this variable could not be isolated.

In no case were idling difficulties encountered. However, at least one previous investigator* has found evidence that although a single cylinder engine will idle with high overlap timing, a multi-cylinder engine with similar timing will not. Although this phenomenon was not investigated in this experiment, it is believed to be due to intake and exhaust system dynamic effects.

* Young, A. W., N.A.C.A., A.P.R. (Nov. 1941).

ENGINE

A single cylinder, C.F.R., high speed, water-cooled engine having a 3.25-inch bore and a 4.50-inch stroke, was used at a compression ratio of 7 to 1. The engine was directly connected to an electric dynamometer which was employed both as a starter and power absorber for the engine, as well as a motor to turn the engine over while measuring friction torque. A shrouded intake valve was used to enhance distribution and mixing of the fresh charge in the cylinder and an Auto Lite B-5 spark plug was used to mitigate any tendencies toward pre-ignition.

FUEL SYSTEM

The fuel system is shown schematically in Figure 2. The fuel was taken from the fuel tank through a small electrically driven pump to a bubble separator and surge tank. Compressed air was pumped into the bubble separator and the pressure was held constant at 30 psi. This air acted as a "cushion" for the system. From the bubble separator the fuel was passed through one of two Fisher and Porter rotometers which had been calibrated by the authors prior to the experiment, as shown by Figure 3. From the rotometers the fuel flowed directly into the vaporizing tank.

AIR SYSTEM

The air system is shown schematically in Figure 2.

EXPERIMENTAL APPARATUS

ENGINE

A single cylinder, 6.75 inch bore, 4.75 inch stroke, engine having a 3.55-inch bore and a 3.55-inch stroke, was used as a compression ratio of 7 to 1. The engine was directly connected to a electric dynamometer which was employed both as a motor and power absorber for the engine, as well as a motor to turn the engine over while measuring friction torque. A shrouded intake valve was used to enhance distribution and mixing of the fresh charge in the cylinder and an auto-lube 5-5 spray pump was used to maintain any tendencies toward pre-ignition.

FUEL SYSTEM

The fuel system is shown schematically in Figure 2. The fuel was taken from the fuel tank through a small electrically driven pump to a bubble meter, rotor and surge tank. Compressed air was pumped into the bubble meter and the pressure was held constant at 10 psi. This air acted as a "cushion" for the system. From the bubble meter the fuel was passed through one of two flash and burner rotameters which had been calibrated by the manufacturer prior to the experiment, as shown by Figure 3. From the rotameters the fuel flowed directly into the reacting tank.

AIR SYSTEM

The air system is shown schematically in Figure 3.

Supercharged air was tapped directly from the laboratory main. It was then taken through two pressure regulators and metered through one of two flat plate orifices with flange taps. The smaller of the two orifices was .515 inches in diameter and the larger was .725 inches in diameter. Both orifices were constructed according to ASME specifications and inserted in 2-inch pipes. After being metered, the air passed through double surge tanks into the vaporizing tank.

VAPORIZING TANK

Air and liquid fuel were introduced into the vaporizing tank separately. The fuel was here vaporized and mixed with the air. The mixture was held at a constant temperature of 140°F . This temperature was controlled by the circulation of steam through heating coils within the tank. From the tank the fresh mixture passed through the throttle valve and into the engine.

OIL SYSTEM AND WATER JACKET SYSTEM

The jacket water temperature was held constant at 212°F . and was controlled by circulating water through a cooler between the condenser and the jacket. The oil temperature was held constant at 140°F . by means of circulating steam or cooling water through the two heat exchangers.

MEASURING INSTRUMENTS

The engine power output was absorbed by a Star electric dynamometer and the brake torque was balanced by a hydraulic

superheated air was tapped directly from the laboratory main. It was then taken through two pressure regulators and metered through one of two 2-inch pipes into the large tank. The smaller of the two outlets was 1 1/2 inches in diameter and was located 7 1/2 inches in diameter. Both outlets were connected to a 2-inch pipe. The air was then passed through a 2-inch pipe into the evaporating tank.

MEASURING THE PRESSURE

The air and liquid fuel were introduced into the evaporating tank separately. The fuel was heated and mixed with the air. The mixture was held at a constant temperature of 140° F. This temperature was controlled by the circulation of steam through heating coils within the tank. From the tank the fresh mixture passed through the throttle valve and into the engine.

OIL SYSTEM AND WATER SYSTEM

The jacket water temperature was held constant at 212° F. and was controlled by circulating water through a cooler between the condenser and the jacket. The oil temperature was held constant at 140° F. by means of circulating steam or cooling water through the two heat exchangers.

MEASURING THE POWER

The engine power output was absorbed by a steel electric dynamometer and the brake torque was balanced by a hydraulic

piston attached through a lever arm to the dynamometer casing. The oil pressure on the hydraulic system was measured in inches of mercury in an open end manometer. The hydraulic system was designed so that one inch of mercury was the equivalent of a one-pound force acting on the hydraulic piston. The reading of the dynamometer scale in inches of mercury was converted to pounds per square inch, brake mean effective pressure. The electric power output from the dynamometer was dissipated through a grid at low outputs and at higher outputs the power was pumped into 110-volt or 220-volt mains, depending upon the magnitude of the power generated.

Detonation was measured qualitatively by employing a detonation pickup in conjunction with a cathode ray oscilloscope. The pickup, a Draper flat diaphragm type with a natural frequency of about 95,000 cycles, was inserted in the cylinder head. The output from this pickup was analyzed and projected on the screen of the oscilloscope as a curve of relative rate of change of cylinder pressure vs time. When conditions of insipient detonation were reached, the curve displayed a definite break or "pip". The operator observing the "pip" also controlled the throttle.

Engine speed was roughly measured by using a tachometer, and for finer speed adjustment a strobotac was employed. Speed was controlled by a drop wire resistance in the shunt field of the dynamometer.

placed attached through a lever arm to the dynamometer. The all pressure on the hydraulic system was applied in inches of mercury in an open end manometer. The dynamometer was designed so that one inch of mercury was equivalent of a one-pound force acting on the piston. The reading of the dynamometer scale in inches of mercury was converted to pounds per square inch, these being effective pressure. The electric power output from the dynamometer was displayed through a dial on low output and at higher output the power was dumped into 110-volt or 220-volt mains, depending upon the magnitude of the power generated.

Excitation was measured, and the frequency of the generator was measured. The pickup, a proper line transformer type with a neutral frequency of about 97,000 cycles, was inserted in the cylinder head. The output from this pickup was amplified and projected on the screen of the oscilloscope as a wave of relative rate of change of cylinder pressure as time. When conditions of incipient detonation were reached, the curve displayed a definite break or "tip". The operator controlling the "tip" also controlled the engine. Engine speed was roughly measured by using a tachometer, and for finer speed adjustment a stopwatch was employed. Speed was controlled by a drop wire resistance in the circuit field of the dynamometer.

PROCEDURE

The following table indicates the operating conditions which were held constant throughout the entire experiment:

Compression ratio	7.0
Fuel-Air ratio	0.08
Spark advance	18° B.T.C.
Oil temperature	140° F.
Water jacket temperature	212° F.
Inlet mixture temperature	140° F.

The following quantities were varied:

Valve overlap	6° - 120°
Manifold pressure	20 - 80 " Hg
RPM	1000 - 3000
Exhaust pressure	30 - 6 " Hg

Each camshaft (with valve timings as per Figure 1) was in turn installed in the engine and two tests were performed. Test no. 1 consisted of varying the R.P.M. and running up the manifold pressure until insipient detonation was reached. Test no. 2 consisted of operating the engine at constant R.P.M. (2000), steadily reducing the exhaust back pressure, and then running up the manifold pressure until insipient detonation was reached. Both of these tests were performed using two fuels (80-octane and di-iso-butylene).

As the insipient detonation points were approached, adjustment of the fuel-air ratio was obtained by computing

EXPERIMENTAL

The following table indicates the operating conditions:

which were held constant throughout the entire experiment:

7.0	Compression ratio
0.08	Yol-Air ratio
18° N.E.C.	Spark advance
140° F.	Oil temperature
215° F.	Water jacket temperature
140° F.	Inlet mixture temperature

The following quantities were varied:

0° - 120°	Valve overlap
20 - 80 " Hg	Manifold pressure
1000 - 3000	RPM
30 - 6 " Hg	Exhaust pressure

Each camshaft (with valve overlap as per Figure 1) was in turn installed in the engine and two tests were performed. Test no. 1 consisted of varying the I.P.M. and running up the manifold pressure until incipient detonation was reached. Test no. 2 consisted of operating the engine at constant I.P.M. (1000), steadily reducing the exhaust back pressure, and then running up the manifold pressure until incipient detonation was reached. Both of these tests were performed using two fuels (80-octane and 62-iso-octane).

As the incipient detonation points were approached, adjustment of the fuel-air ratio was obtained by computing

the mass of air flow by the orifice equation, entering the rotometer calibration chart with the mass of fuel flow desired to give a fuel-air ratio of .08, and adjusting the fuel flow until the rotometer showed the proper scale reading. The manifold pressure was then varied until insipient detonation occurred. The above procedure was repeated until a "no change" condition was reached.

the mass of air flow by the orifice equation, and using the
 rotometer calibration chart with the mass of air flow de-
 rived to give a fuel-air ratio of 14.08, and adjusting the
 fuel flow until the rotometer showed the proper value read-
 ing. The manifold pressure was then varied until the desired
 detonation occurred. The above procedure was repeated until
 a "no change" condition was reached.

DISCUSSION (80 OCTANE)

From Fig. 6 it is noted that as the residual gas is "sucked" out of the cylinder due to decreasing the back pressure, the allowable P_i is progressively lowered in the case of the 6° overlap cam, and it is therefore apparent that residual gas has an inhibiting effect on detonation.

Still referring to Fig. 6, it might reasonably follow that if this is true, the higher overlaps should give even less detonation limited P_i . However, in the case of the higher overlaps, more fresh mixture is consumed per cycle, tending to cool the engine parts. This increased cooling may overshadow the effect of reduced residual gas and thereby permit higher allowable P_i 's.

Referring to Fig. 4, it is noted that at low speed (1000 RPM), higher overlaps permit higher allowable P_i 's. At this speed the inlet pressure is always less than the exhaust pressure. Since the mixture consumption per cycle is approximately constant (at 1000 RPM), as seen by Fig. 9, differences in engine parts temperature due to this effect are negligible. However, two other effects influence the amount of residual back flow, (a) the pressure gradient between P_e and P_i , and (b) the overlap which changes the time available for the back flow to take place. If it is assumed that residual gas acts as an inhibitor, it follows that at 1000 RPM the residual gas content is progressively higher with greater overlaps. As the engine speed is in-

creased, both the pressure gradient and the time available for scavenging are reduced, and at 3000 RPM all overlaps show approximately the same detonation limited P_i 's.

Fig. 8 indicates that overlap has little effect on detonation limited IHP at low speed, but that overlap increases the IHP appreciably at 3000 RPM. It is to be noted that at this speed the highest overlap gives the maximum power, but that a reduction in overlap of 50% reduces the power by only 7%.

At 2000 RPM, Fig. 7 indicates that for all overlaps greater than 60° , the variation of IHP with altitude is negligible. If these runs had been conducted at a lower speed, the overlap effect might have become more pronounced due to greater time available for purging, or back flow, as the case might be.

Fig. 8 indicates that low overlaps have the better volumetric efficiencies at low speed, but that a reversal takes place such that the high overlaps give the better volumetric efficiencies at high speed. This reversal is due to the fact that at low speed P_i is less than P_e , while at high speed P_i is greater than P_e (Fig. 4).

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DISCUSSION (DI-ISO-BUTYLENE)

In the case of di-iso-butylene, the determination of insipient detonation was exceedingly more difficult than in the case of 80-octane. During the early stages of operation, the authors were somewhat deceived by what was observed on the oscilloscope. When the inlet pressure was increased to the point where a distinct "pip" was observed on the scope, it was assumed that insipient detonation was reached in that the pip resembled that obtained when insipient detonation occurred with 80-octane. However, it was later discovered that after the initial "pip" appeared, its intensity was unaltered by either radical changes in spark timing or large increases of manifold pressure (in the order of magnitude of 12 to 18 inches of Hg). After this discovery, the initial "pip" was disregarded and insipient detonation was only assumed to be present when an increase in manifold pressure noticeably increased the "pip's" magnitude. This fact necessitated a re-run of the 6° overlap shaft on di-iso-butylene for varying RPM's and the re-run was performed at the conclusion of the other runs. However, the new data was erringly placed in table I and also appears in figure 13 for the low overlap. These four points should be raised by about 15" Hg.

The running of di-iso-butylene in addition to 80-octane was undertaken to determine if the commonly observed reversal of critical pressure-speed relations, as compared with 80-octane, would persist in the case of large variations in

residual gas concentration. It was suspected that residual gases might exert either a catalytic or an inhibiting effect on the auto ignition of the last part of the charge to burn. At the time of this investigation, the effect of residual content on time reversal was being concurrently studied by Lieutenant Commander J. M. Richards, et al, under carefully controlled experimental conditions and it was anticipated that the two investigations would perhaps substantiate each other through the viewpoint of different experimental parameters. The work of Richards, et al, showed conclusively that residual gas has no appreciable effect either as a catalyst or as an inhibitor on the observed reversal. Although the investigation presented herein also shows the reversal (Fig. 10), no theory can be propounded by this experiment in view of the fact that residual gas effects are negligible. Sloan Laboratories, M.I.T., have shown the reversal to be due to a time effect (rapidity of compression).

It is believed by the authors that for similar investigations in the future, better results might be obtained by increasing the inlet temperature of the fresh mixture above 140°F since this fuel is relatively insensitive to pressure.

As observed from Figs. 11 and 12, the effect of overlap on detonation limited PI is negligible with a slight tendency toward higher PI's for higher overlap in the case of 80-octane and lower PI's for the high overlaps with di-iso-butylene.

The IHP is progressively greater for higher overlaps at 1000-1100 RPM, and at increasing speeds the effect of overlap

[illegible]

becomes less important since the IMEP is substantially constant (Fig. 8). It is believed certain that the 120° overlap point at 2100 RPM (Fig. 8) is considerably in error and that the IMEP for this point should be about 185, as shown by Fig. 7 at $P_c \approx 30$ and $RPM \approx 2000$. The error is unquestionably due to a personnel oversight. Time permitting, this shaft would be inserted in the engine and the point recomputed.

Fig. 15 indicates extensive blow through for the high overlap cam at 1100 RPM.

CONCLUSIONS (80-OCTANE)

For maximum detonation limited IHP optimum valve overlap depends upon engine speed.

Overlap has little effect on detonation limited IHP at low speed.

Higher overlaps give higher allowable IHP's at high speed.

No appreciable gain is obtained in the indicated output for overlaps greater than 60° .

At a speed of 2000 RPM the indicated output changes negligibly with decreases in back pressure for all overlaps of 60° or greater.

Residual gas has an inhibiting effect on the detonation tendencies of this fuel.

It has previously been established that residual gas acts as an inhibitor in the case of iso-octane fuel.*

* N.A.C.A., T.R. #699 (1940).

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For maximum efficiency in the
overhead department the
overhead was fixed at
at low speed.
Higher overheads are
speed.

No appreciable change in
output for overheads between
at a speed of 1000 and 2000
notably with overheads at 1000
rate of 60° or greater.
Residual has been calculated
also condensed of this test.
It has previously been
case in an illustration in the case of low-speed test.

CONCLUSIONS (DI-ISO-BUTYLENE)

This fuel, as compared with 80-octane, permits higher detonation limited inlet pressure and higher engine output under all conditions investigated.

This fuel is relatively insensitive to pressure.

As the speed is increased, the allowable fresh mixture consumption per cycle is reduced, resulting in the peak pressure reversal observed by previous investigators.

No conclusion is drawn as to the effect of residual gas on the detonation characteristics of this fuel.

The high allowable PI at low speeds causes excessive "blow through" when using the 120° overlap cam.

Valve overlap has relatively little effect on detonation limited inlet pressure.

Greater overlaps permit the development of higher IHP's at low speed, but as the speed is increased, the IHP is substantially constant for all overlaps.

1700-1800 1800-1900 1900-2000 2000-2100 2100-2200 2200-2300 2300-2400 2400-2500 2500-2600 2600-2700 2700-2800 2800-2900 2900-3000 3000-3100 3100-3200 3200-3300 3300-3400 3400-3500 3500-3600 3600-3700 3700-3800 3800-3900 3900-4000 4000-4100 4100-4200 4200-4300 4300-4400 4400-4500 4500-4600 4600-4700 4700-4800 4800-4900 4900-5000 5000-5100 5100-5200 5200-5300 5300-5400 5400-5500 5500-5600 5600-5700 5700-5800 5800-5900 5900-6000 6000-6100 6100-6200 6200-6300 6300-6400 6400-6500 6500-6600 6600-6700 6700-6800 6800-6900 6900-7000 7000-7100 7100-7200 7200-7300 7300-7400 7400-7500 7500-7600 7600-7700 7700-7800 7800-7900 7900-8000 8000-8100 8100-8200 8200-8300 8300-8400 8400-8500 8500-8600 8600-8700 8700-8800 8800-8900 8900-9000 9000-9100 9100-9200 9200-9300 9300-9400 9400-9500 9500-9600 9600-9700 9700-9800 9800-9900 9900-10000 10000-10100 10100-10200 10200-10300 10300-10400 10400-10500 10500-10600 10600-10700 10700-10800 10800-10900 10900-11000 11000-11100 11100-11200 11200-11300 11300-11400 11400-11500 11500-11600 11600-11700 11700-11800 11800-11900 11900-12000 12000-12100 12100-12200 12200-12300 12300-12400 12400-12500 12500-12600 12600-12700 12700-12800 12800-12900 12900-13000 13000-13100 13100-13200 13200-13300 13300-13400 13400-13500 13500-13600 13600-13700 13700-13800 13800-13900 13900-14000 14000-14100 14100-14200 14200-14300 14300-14400 14400-14500 14500-14600 14600-14700 14700-14800 14800-14900 14900-15000 15000-15100 15100-15200 15200-15300 15300-15400 15400-15500 15500-15600 15600-15700 15700-15800 15800-15900 15900-16000 16000-16100 16100-16200 16200-16300 16300-16400 16400-16500 16500-16600 16600-16700 16700-16800 16800-16900 16900-17000 17000-17100 17100-17200 17200-17300 17300-17400 17400-17500 17500-17600 17600-17700 17700-17800 17800-17900 17900-18000 18000-18100 18100-18200 18200-18300 18300-18400 18400-18500 18500-18600 18600-18700 18700-18800 18800-18900 18900-19000 19000-19100 19100-19200 19200-19300 19300-19400 19400-19500 19500-19600 19600-19700 19700-19800 19800-19900 19900-20000 20000-20100 20100-20200 20200-20300 20300-20400 20400-20500 20500-20600 20600-20700 20700-20800 20800-20900 20900-21000 21000-21100 21100-21200 21200-21300 21300-21400 21400-21500 21500-21600 21600-21700 21700-21800 21800-21900 21900-22000 22000-22100 22100-22200 22200-22300 22300-22400 22400-22500 22500-22600 22600-22700 22700-22800 22800-22900 22900-23000 23000-23100 23100-23200 23200-23300 23300-23400 23400-23500 23500-23600 23600-23700 23700-23800 23800-23900 23900-24000 24000-24100 24100-24200 24200-24300 24300-24400 24400-24500 24500-24600 24600-24700 24700-24800 24800-24900 24900-25000 25000-25100 25100-25200 25200-25300 25300-25400 25400-25500 25500-25600 25600-25700 25700-25800 25800-25900 25900-26000 26000-26100 26100-26200 26200-26300 26300-26400 26400-26500 26500-26600 26600-26700 26700-26800 26800-26900 26900-27000 27000-27100 27100-27200 27200-27300 27300-27400 27400-27500 27500-27600 27600-27700 27700-27800 27800-27900 27900-28000 28000-28100 28100-28200 28200-28300 28300-28400 28400-28500 28500-28600 28600-28700 28700-28800 28800-28900 28900-29000 29000-29100 29100-29200 29200-29300 29300-29400 29400-29500 29500-29600 29600-29700 29700-29800 29800-29900 29900-30000 30000-30100 30100-30200 30200-30300 30300-30400 30400-30500 30500-30600 30600-30700 30700-30800 30800-30900 30900-31000 31000-31100 31100-31200 31200-31300 31300-31400 31400-31500 31500-31600 31600-31700 31700-31800 31800-31900 31900-32000 32000-32100 32100-32200 32200-32300 32300-32400 32400-32500 32500-32600 32600-32700 32700-32800 32800-32900 32900-33000 33000-33100 33100-33200 33200-33300 33300-33400 33400-33500 33500-33600 33600-33700 33700-33800 33800-33900 33900-34000 34000-34100 34100-34200 34200-34300 34300-34400 34400-34500 34500-34600 34600-34700 34700-34800 34800-34900 34900-35000 35000-35100 35100-35200 35200-35300 35300-35400 35400-35500 35500-35600 35600-35700 35700-35800 35800-35900 35900-36000 36000-36100 36100-36200 36200-36300 36300-36400 36400-36500 36500-36600 36600-36700 36700-36800 36800-36900 36900-37000 37000-37100 37100-37200

1. The first part of the document is a letter from the President of the United States to the Congress, dated January 1, 1861. It is a formal communication, and it is written in a very dignified and official style. The President expresses his regret that he cannot deliver a personal message to the Congress, and he explains the reasons for this. He then proceeds to discuss the state of the Union, and he mentions the recent events of the secession of the Southern States. He expresses his confidence in the future of the Union, and he urges the Congress to take prompt action to preserve the Union.

THEY ARE ESSENTIALLY CONSIDERED FOR PROSECUTION OF ANY
INVESTIGATION OF THE CASE, BUT AS THE CASE IS NOT
CLOSED OVERLAP BETWEEN THE TWO INVESTIGATIONS
WILL BE THEREFORE, THE TWO INVESTIGATIONS
WILL BE CONSIDERED AS ONE AND THE SAME.

SYMBOLS

B.L.	Brake loading	"Hg.
e	Volumetric efficiency	-
FL	Friction loading	"Hg.
F/A	Fuel air ratio	-
Fuel Cons.	Fuel consumption	#/sec.
Imep	Indicated mean effective pressure	Psia.
IHP	Indicated horse power	H.P.
Isfc	Indicated specific fuel consumption	$\frac{\text{# fuel}}{\text{IHP-hr.}}$
Ma	Air consumption	#/sec.
O	Orifice in use	-
ΔP	Pressure across air orifice	"H ₂ O
Pb	Pressure before air orifice (abs.)	"Hg.
Pe	Exhaust manifold pressure (abs.)	"Hg.
Pi	Inlet manifold pressure (abs.)	"Hg.
R	Rotometer in use	-
Roto	Rotometer reading	-
Tb	Temp. before air orifice	°F
Vd	Engine displacement volume (37.33 cu.in.)	-
ρi	Inlet mixture density	$\frac{\text{lb}}{\text{ft}^3}$

61	Inlet mixture density	1.0
70	Engine displacement volume (cc./min.)	1.0
75	Temp. before air valve	1.0
80	Rotometer reading	1.0
85	Rotometer in use	1.0
90	Inlet manifold pressure (psia)	1.0
95	Exhaust manifold pressure (psia)	1.0
100	Pressure before air valve (psia)	1.0
105	Pressure across air valve	1.0
110	Orifice in use	1.0
115	Air consumption	1.0
120	Indicated specific fuel consumption	1.0
125	Indicated horse power	1.0
130	Indicated mean effective pressure	1.0
135	Fuel consumption	1.0
140	Fuel air ratio	1.0
145	Friction loss	1.0
150	Volometric efficiency	1.0
155	Inake loss	1.0

EQUATIONS

For .515" orifice:

$$\text{Air consumption} = .01825 \left(\frac{P_b \times \Delta P}{T_b + 460} \right)^{\frac{1}{2}}$$

For .725" orifice:

$$\text{Air consumption} = .0365 \left(\frac{P_b \times \Delta P}{T_b + 460} \right)^{\frac{1}{2}}$$

$$\text{Fuel consumption} = (0.08) \times \text{Air consumption}$$

$$\text{Imep} = (\text{BL} + \text{FL})(4.245)$$

$$\text{IHP} = \frac{(\text{BL} + \text{FL})(\text{RPM})}{5000}$$

$$\text{Isfc} = \frac{\# \text{ fuel/hr}}{\text{IHP}}$$

$$\eta = \frac{(\text{Const.}) M_a}{P_i \times V_d \times \text{RPM}}$$

1000000

For 212" orifice:

$$\text{Air consumption} = 0.0002 \left(\frac{212}{100} \right)^2 \times \frac{1}{0.0004} = 0.0002 \times 4.48 = 0.0009$$

For 232" orifice:

$$\text{Air consumption} = 0.0002 \left(\frac{232}{100} \right)^2 \times \frac{1}{0.0004} = 0.0002 \times 5.38 = 0.0011$$

Total consumption = (0.0009 + 0.0011) x 100 = 0.0020

$$\text{Imp} = (EL + EL)(4.242)$$

$$\text{Imp} = \frac{(EL + EL)(4.242)}{2000}$$

$$\text{Rate} = \frac{\text{Imp}}{\text{Imp}}$$

$$Q = \frac{(\text{Const.}) \times \text{Rate}}{1 \times 10 \times 1000}$$

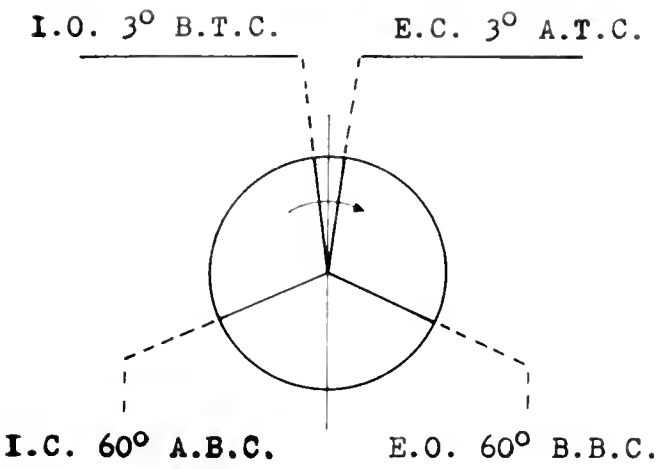
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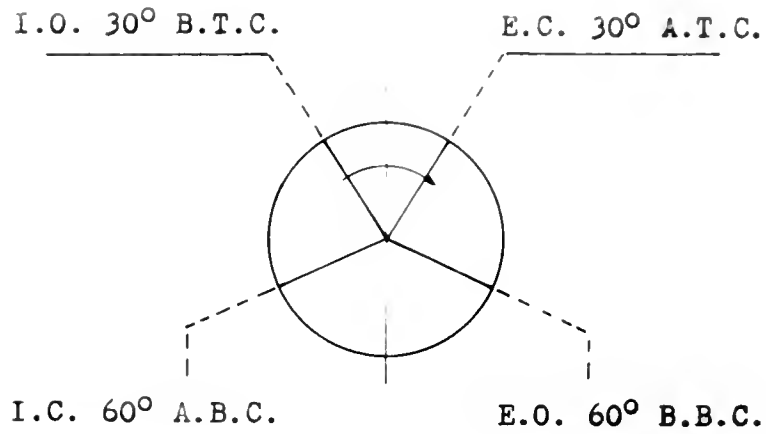
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6. NACA, A.P.R., November 1941 (L. H. Young).

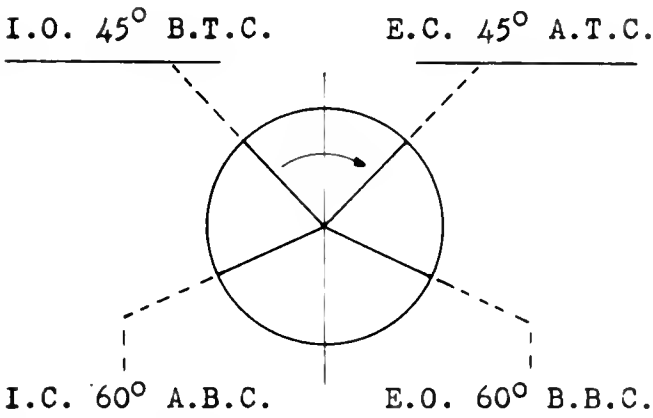
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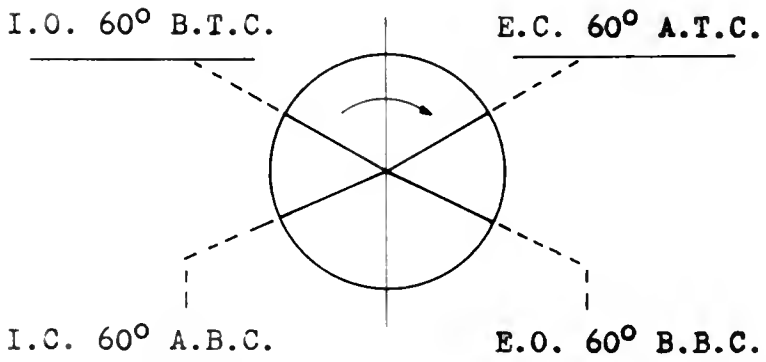
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CAM NO. 3

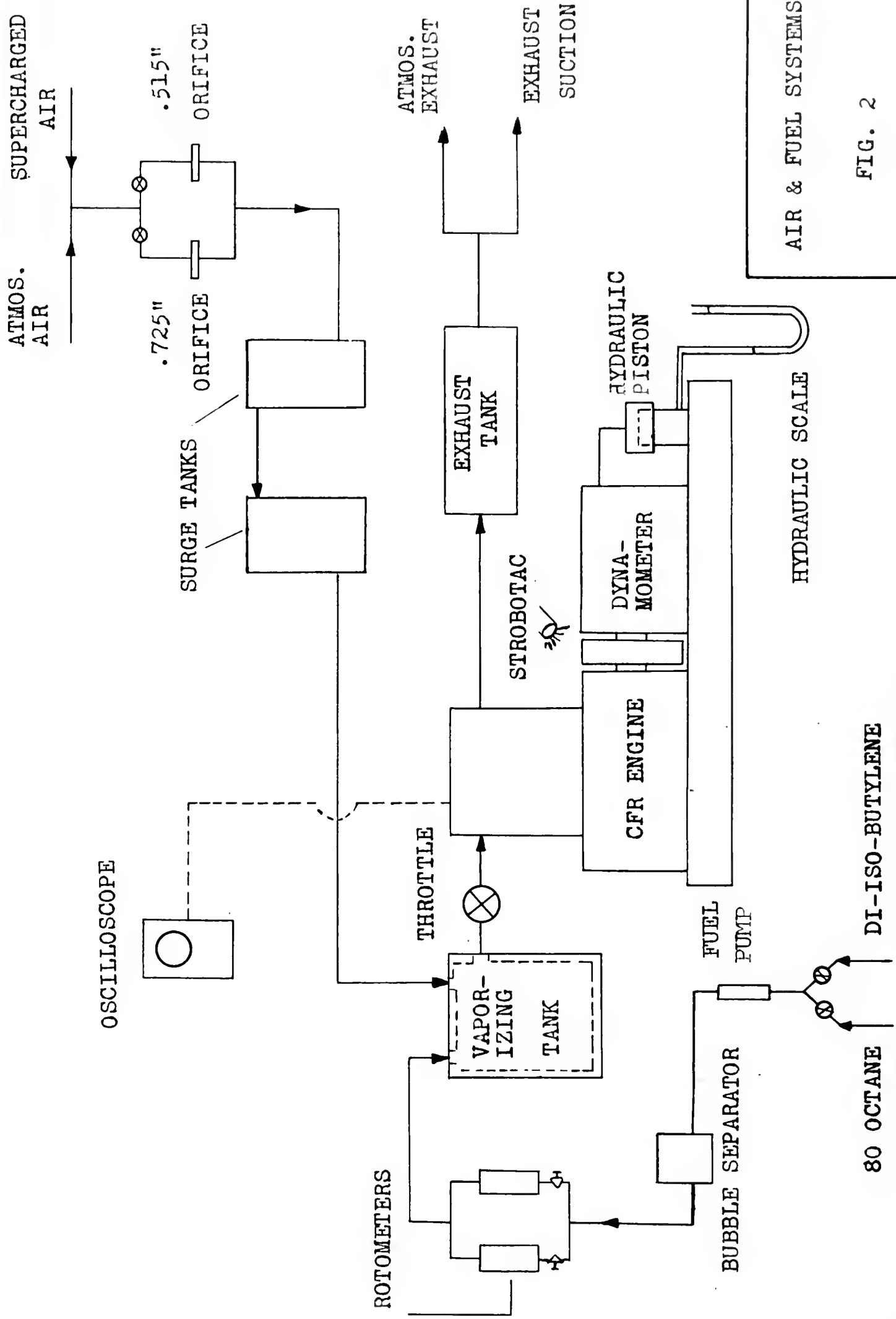


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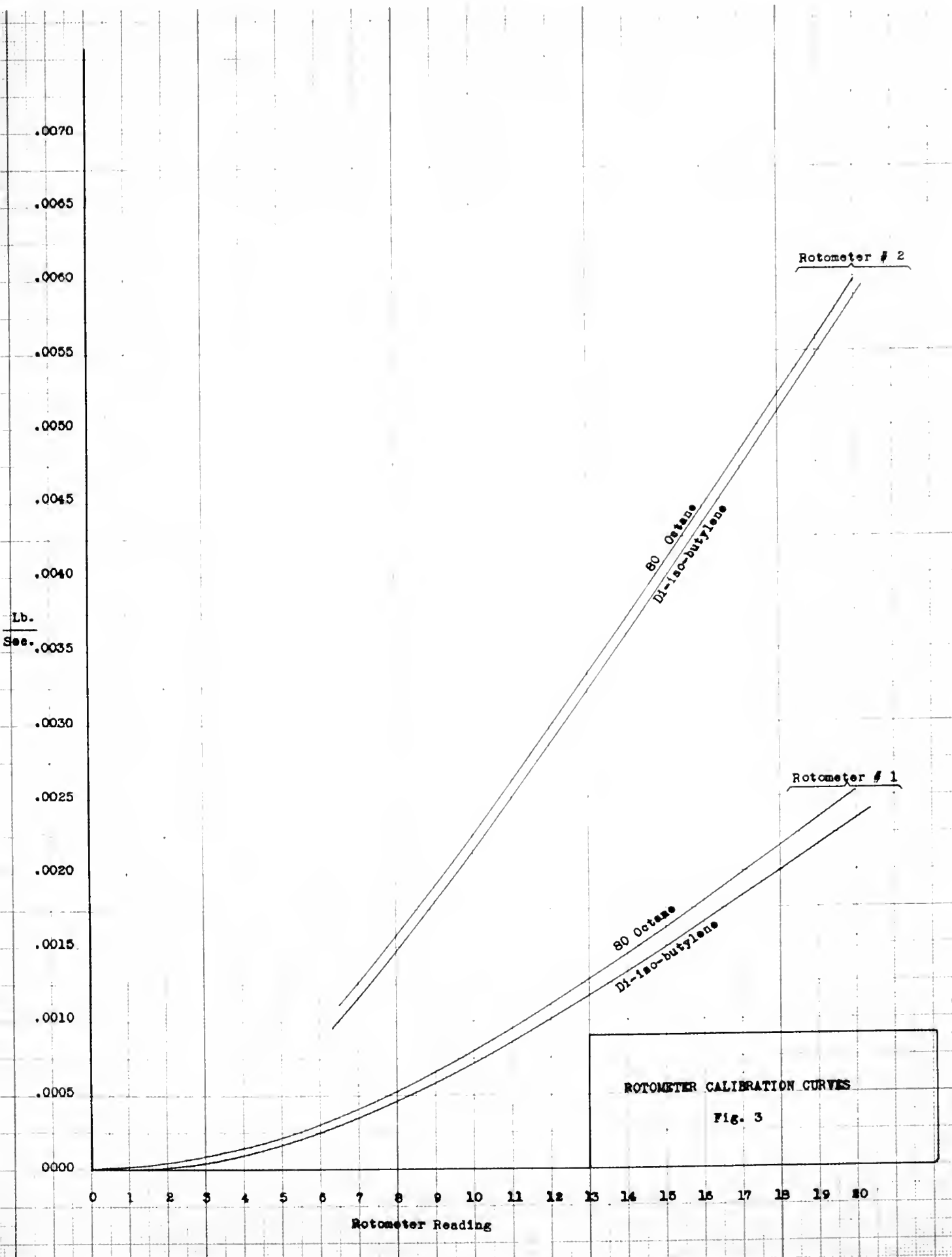
CAMSHAFT TIMING DIAGRAMS
FIG. 1



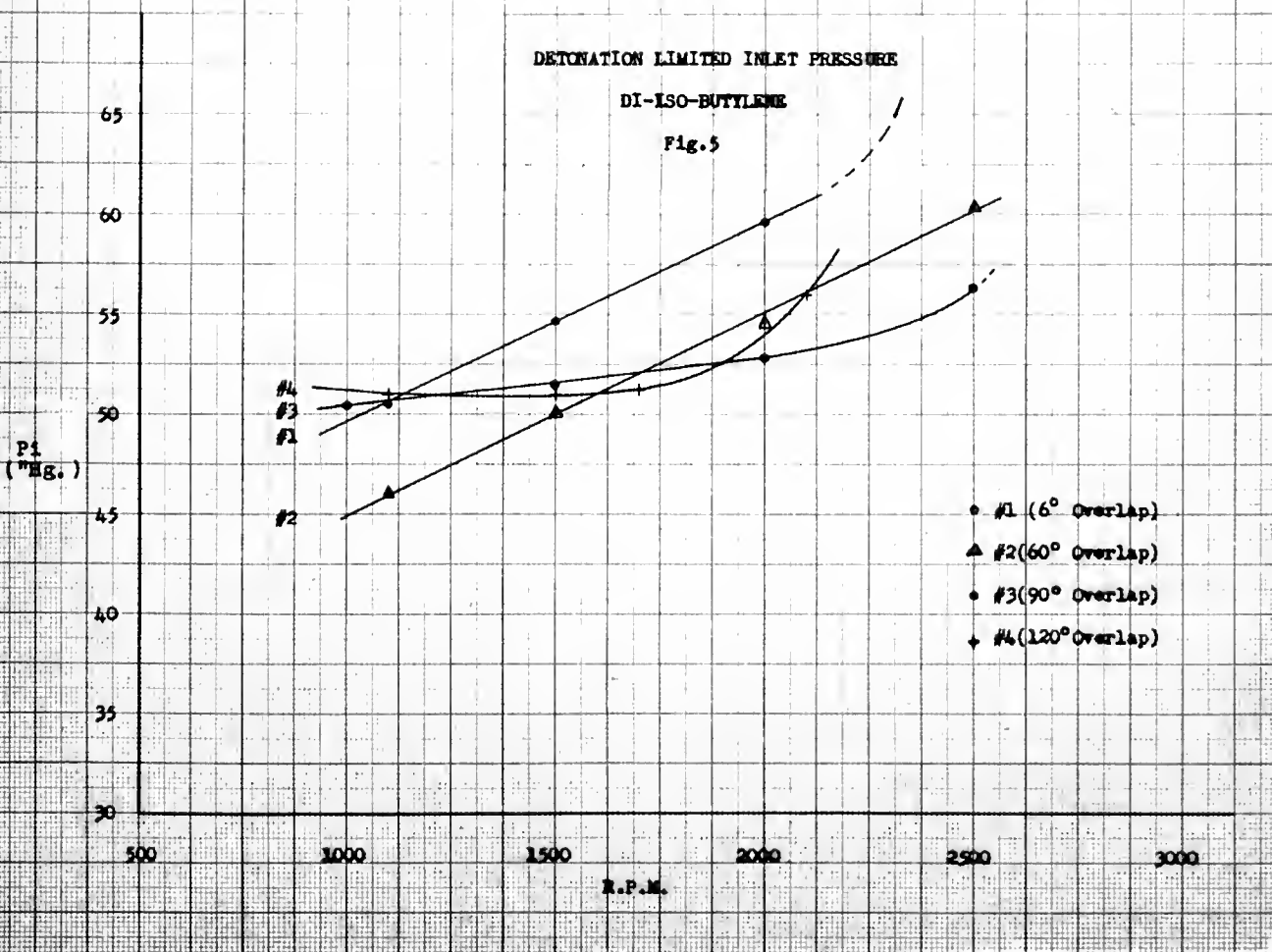
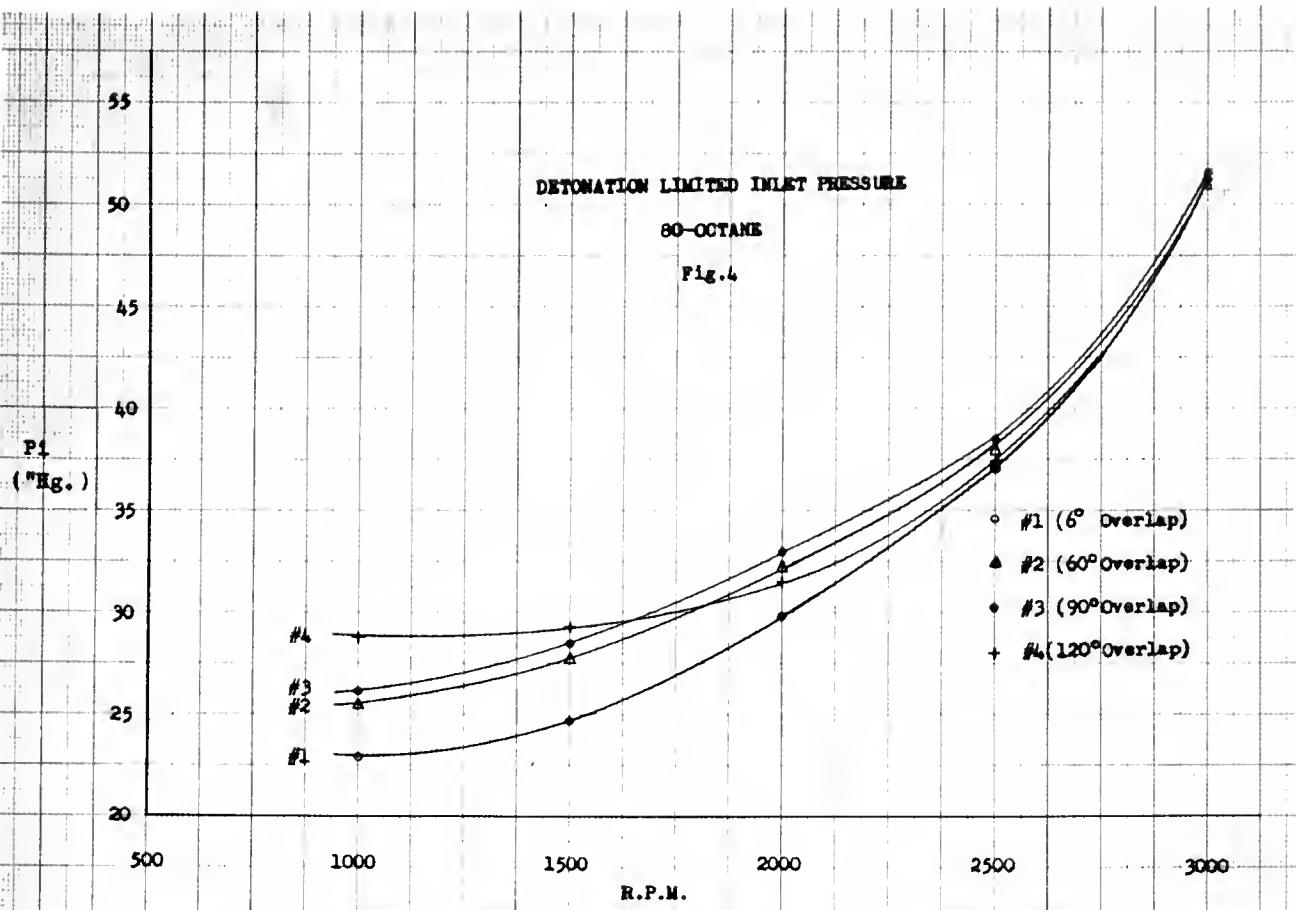


AIR & FUEL SYSTEMS

FIG. 2

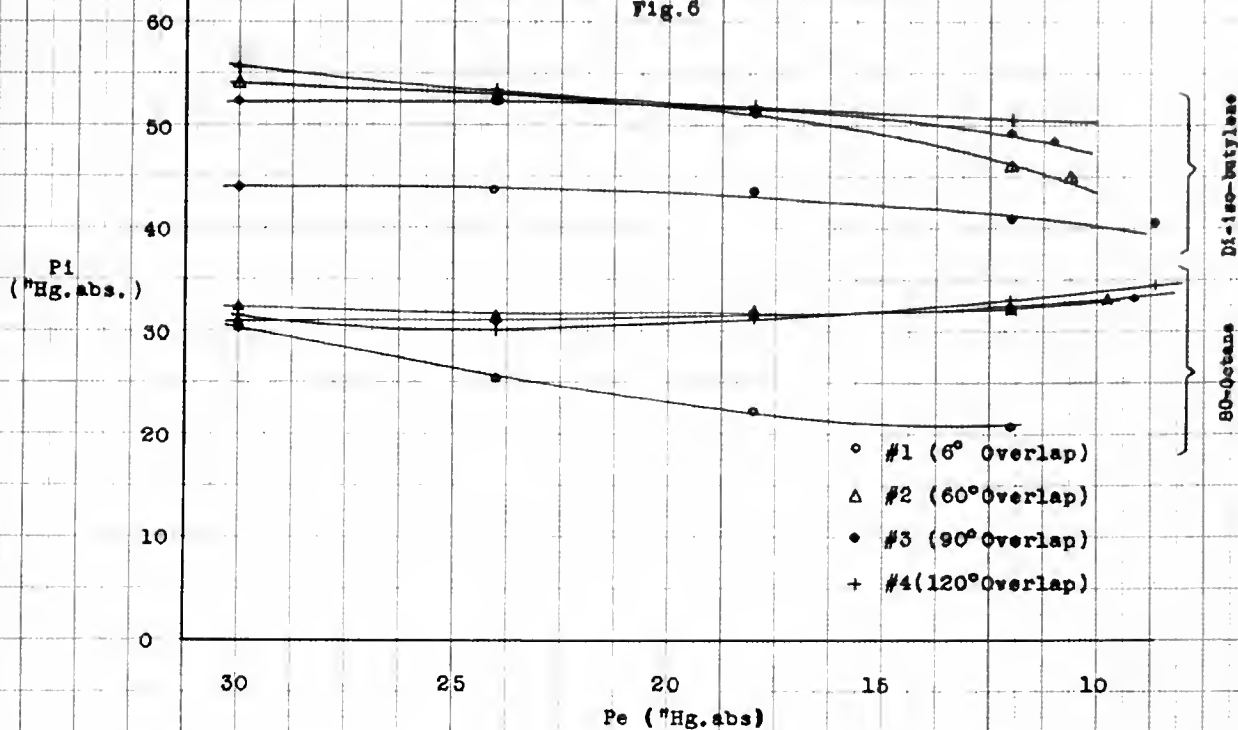






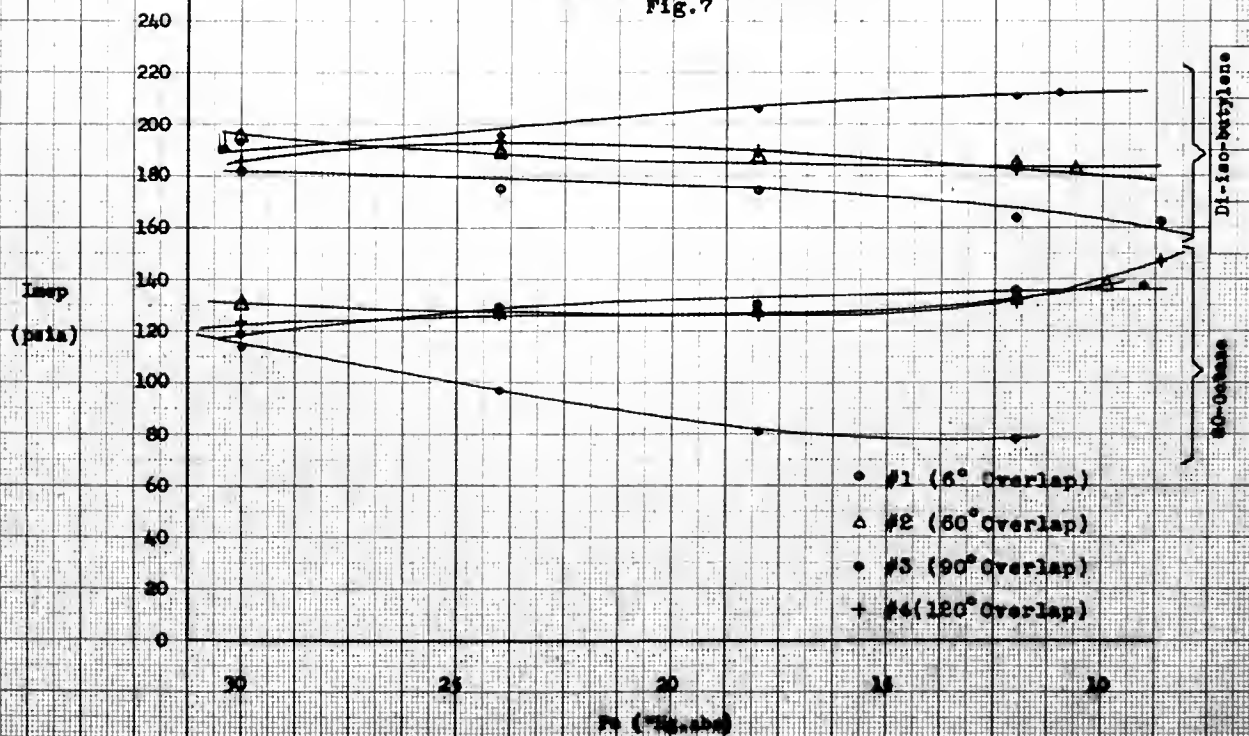
DETONATION LIMITED INLET PRESSURE

Fig.6



DETONATION LIMITED Imep

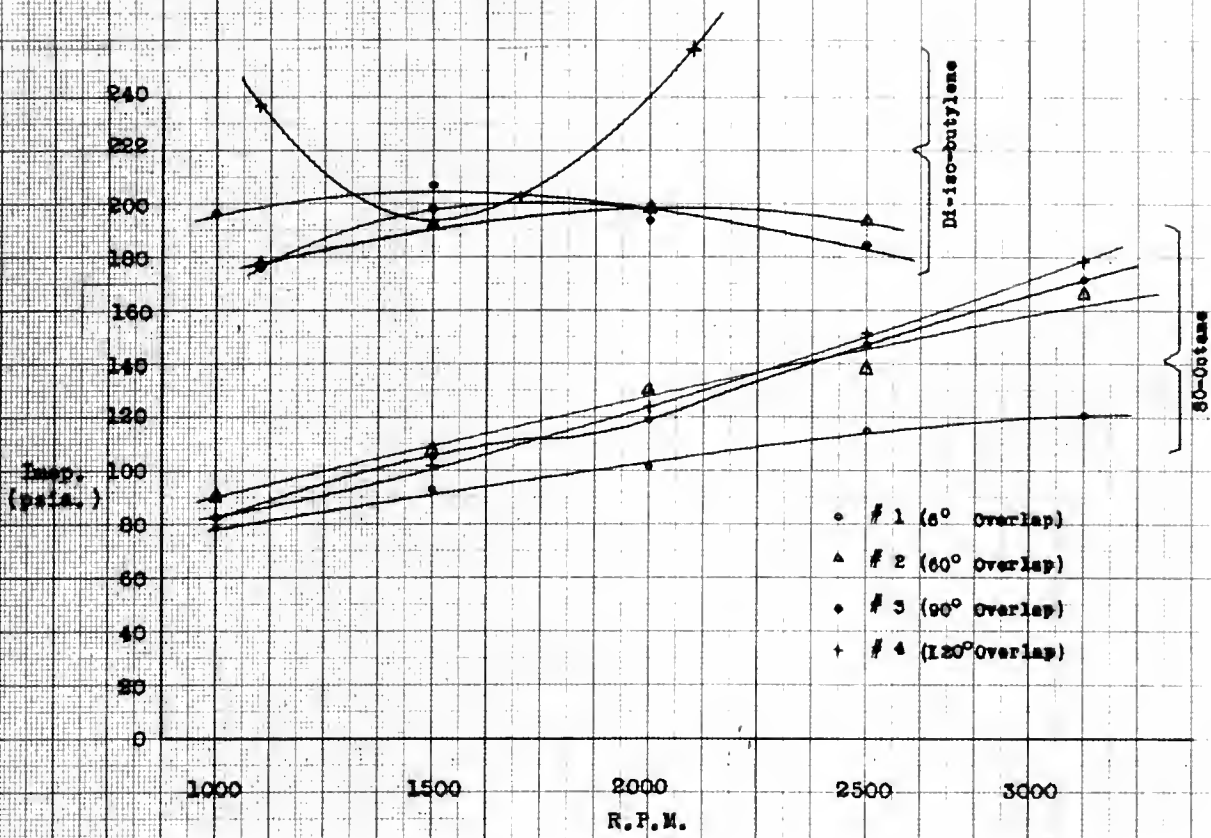
Fig.7



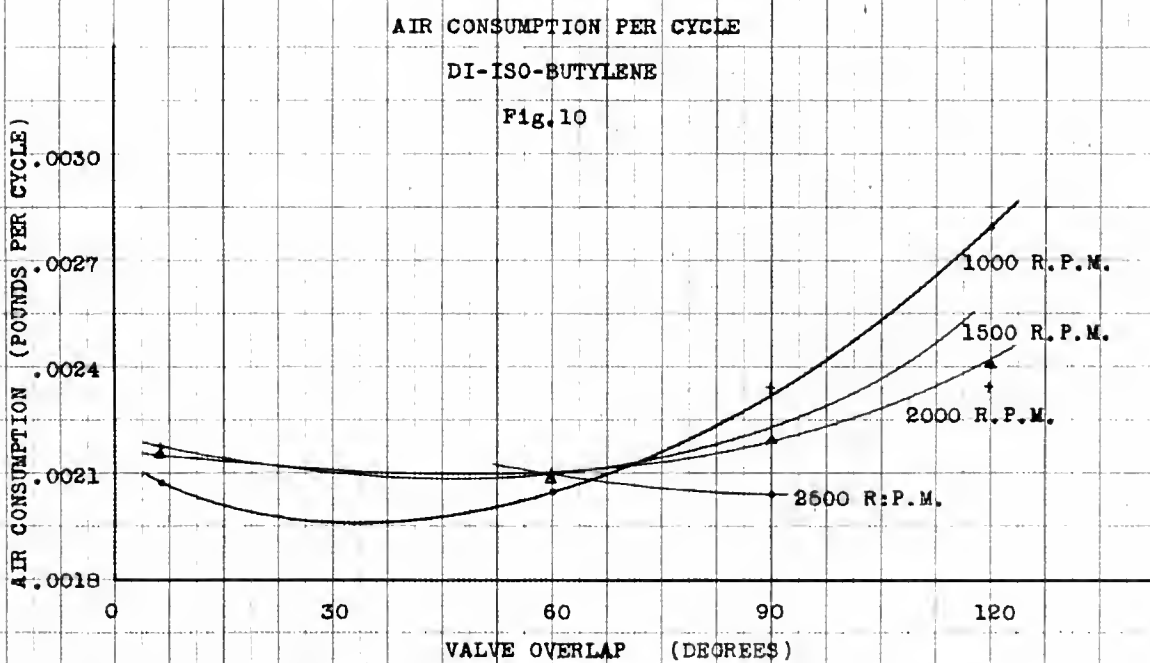
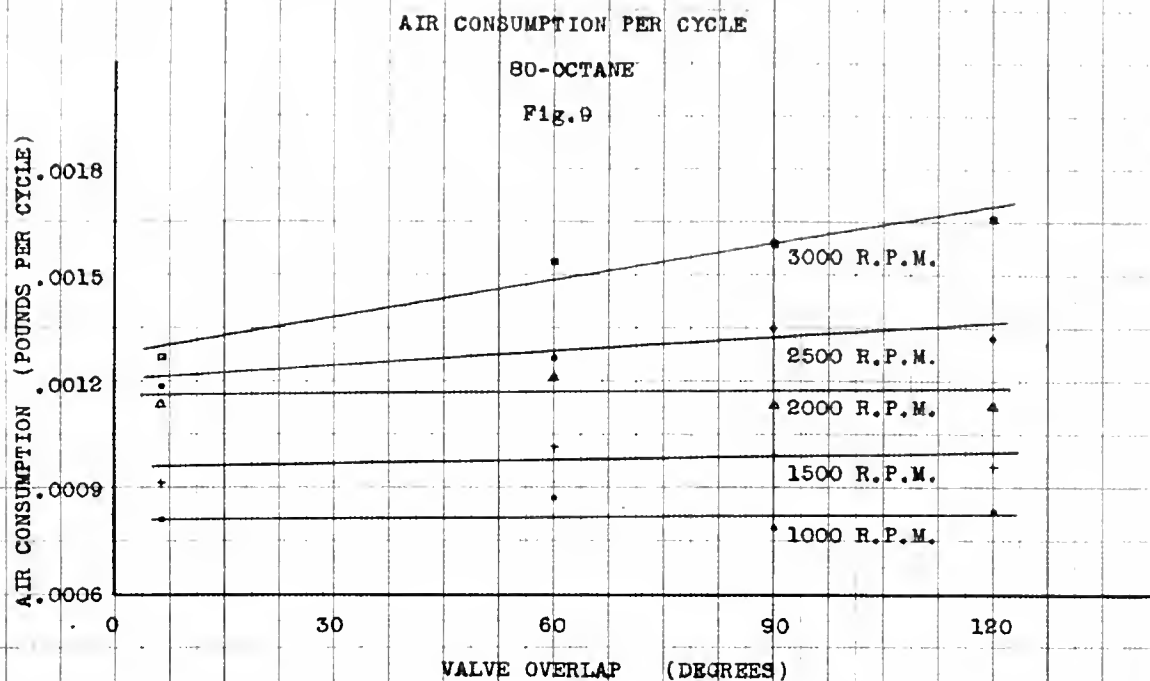


DETONATION LIMITED Imep.

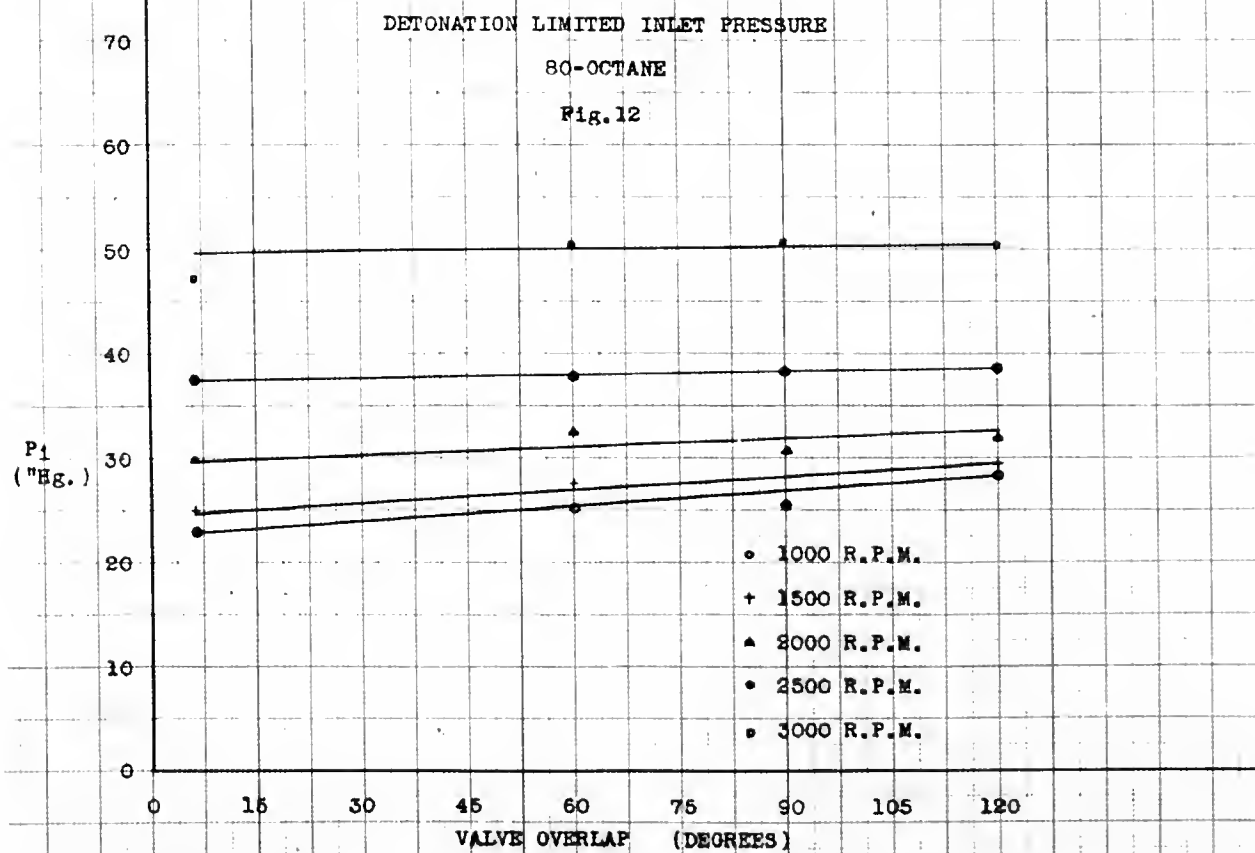
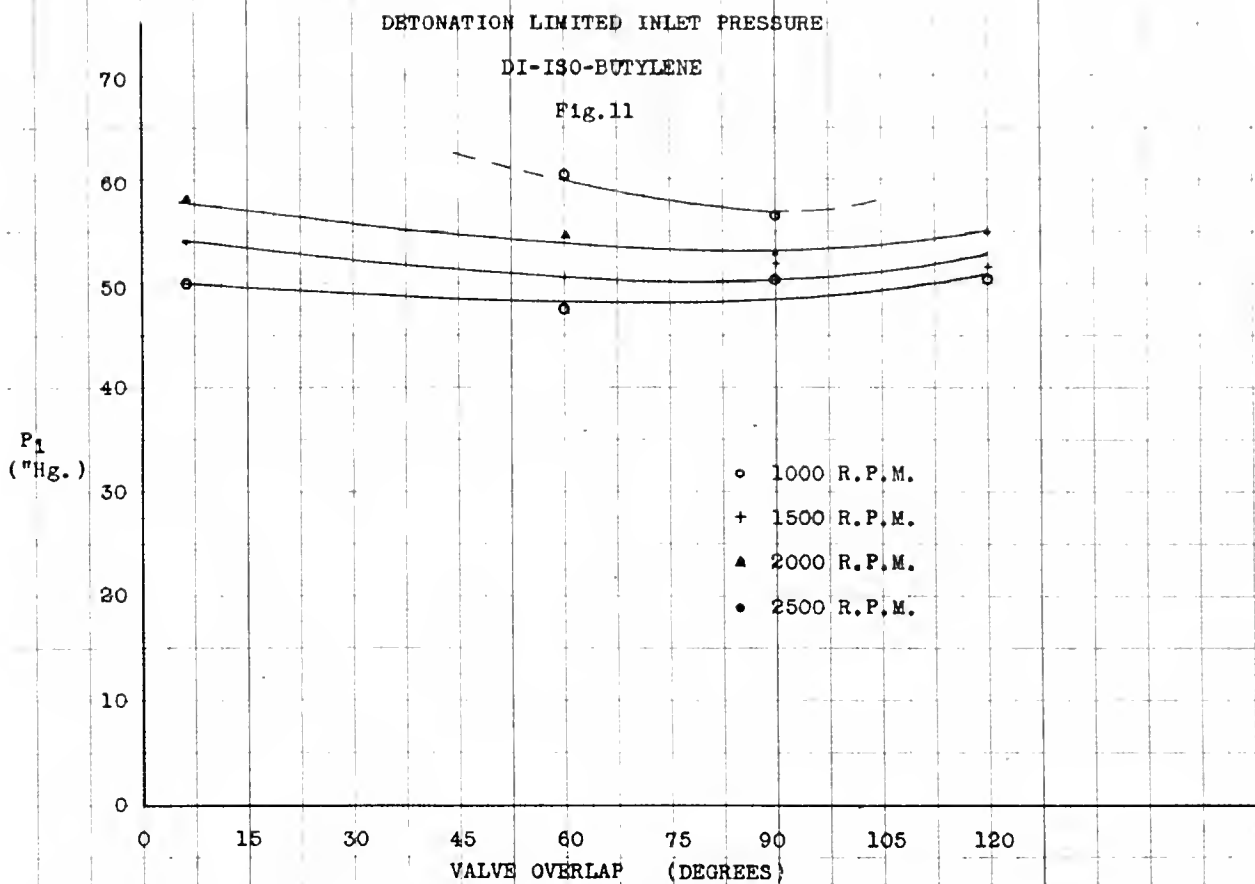
Fig. 8









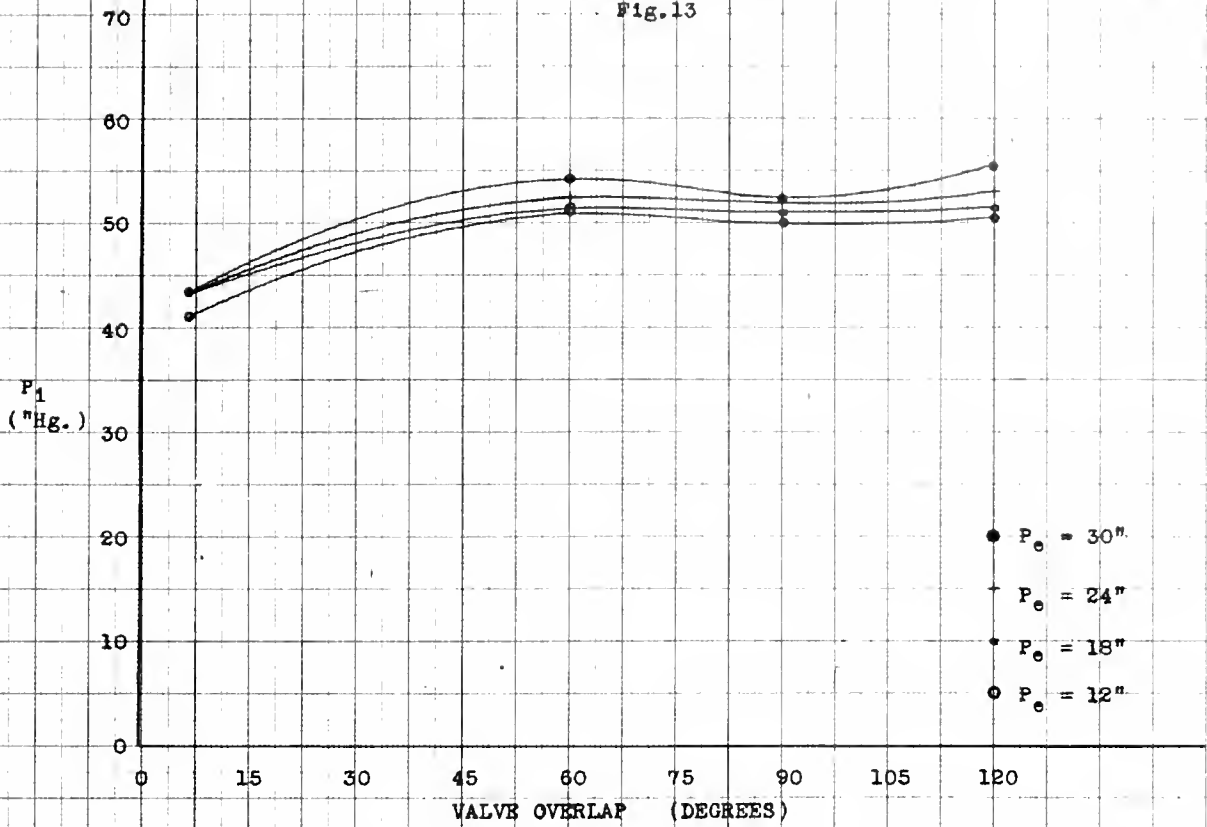




DETONATION LIMITED INLET PRESSURE

DI-ISO-BUTYLENE

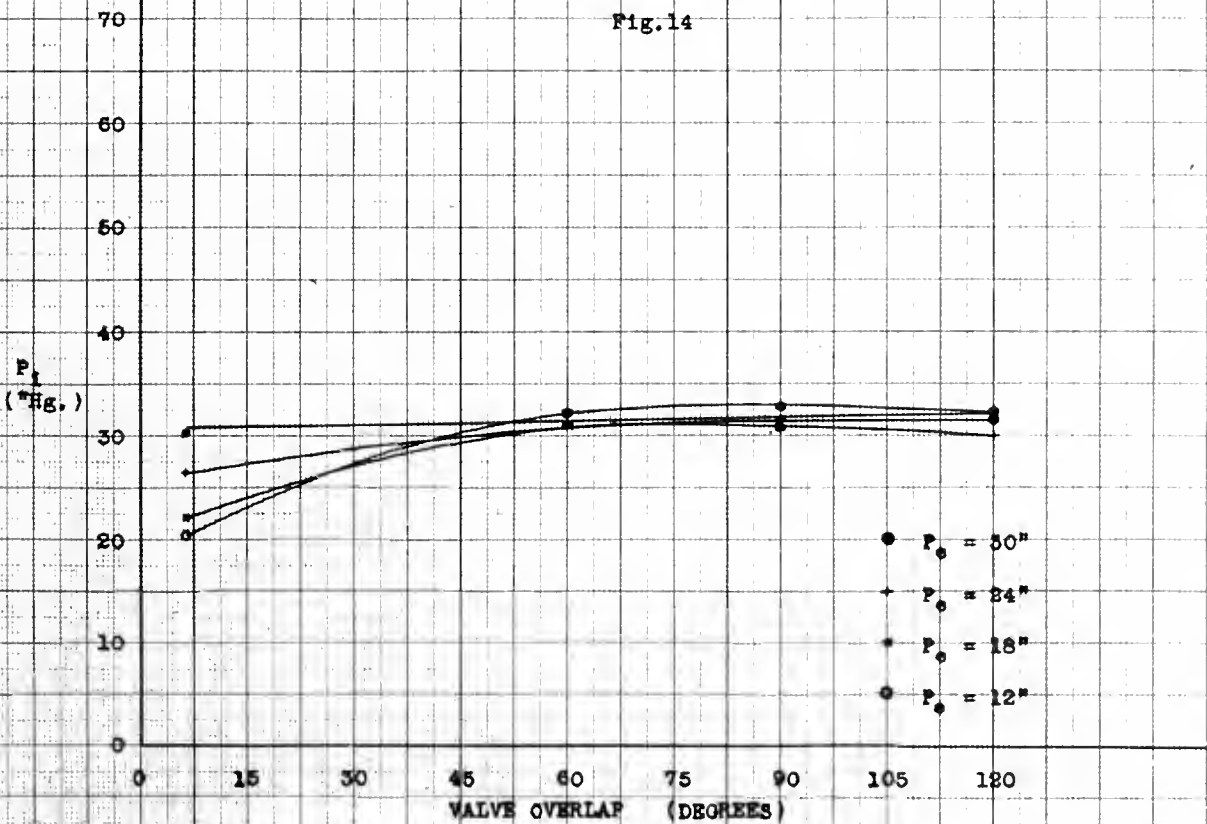
Fig.13



DETONATION LIMITED INLET PRESSURE

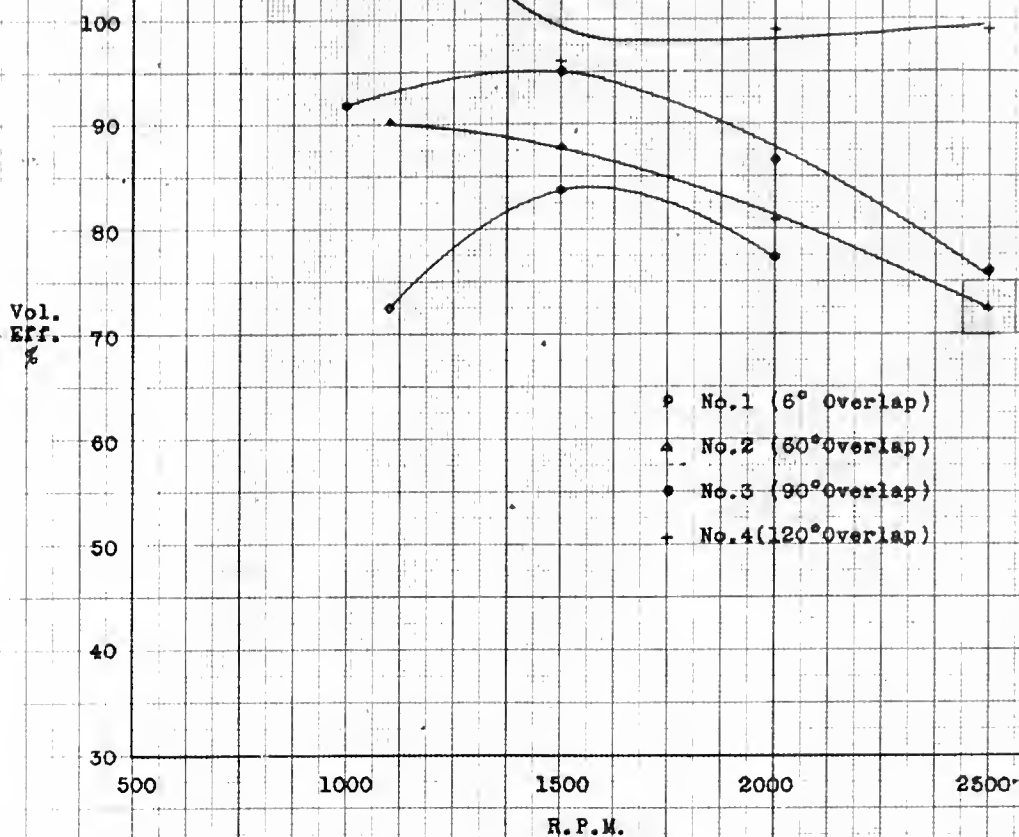
80-OCTANE

Fig.14





VOLUMETRIC EFFICIENCY
DI-ISO-BUTYLENE
Fig.15



VOLUMETRIC EFFICIENCY
80-OCTANE
Fig.16

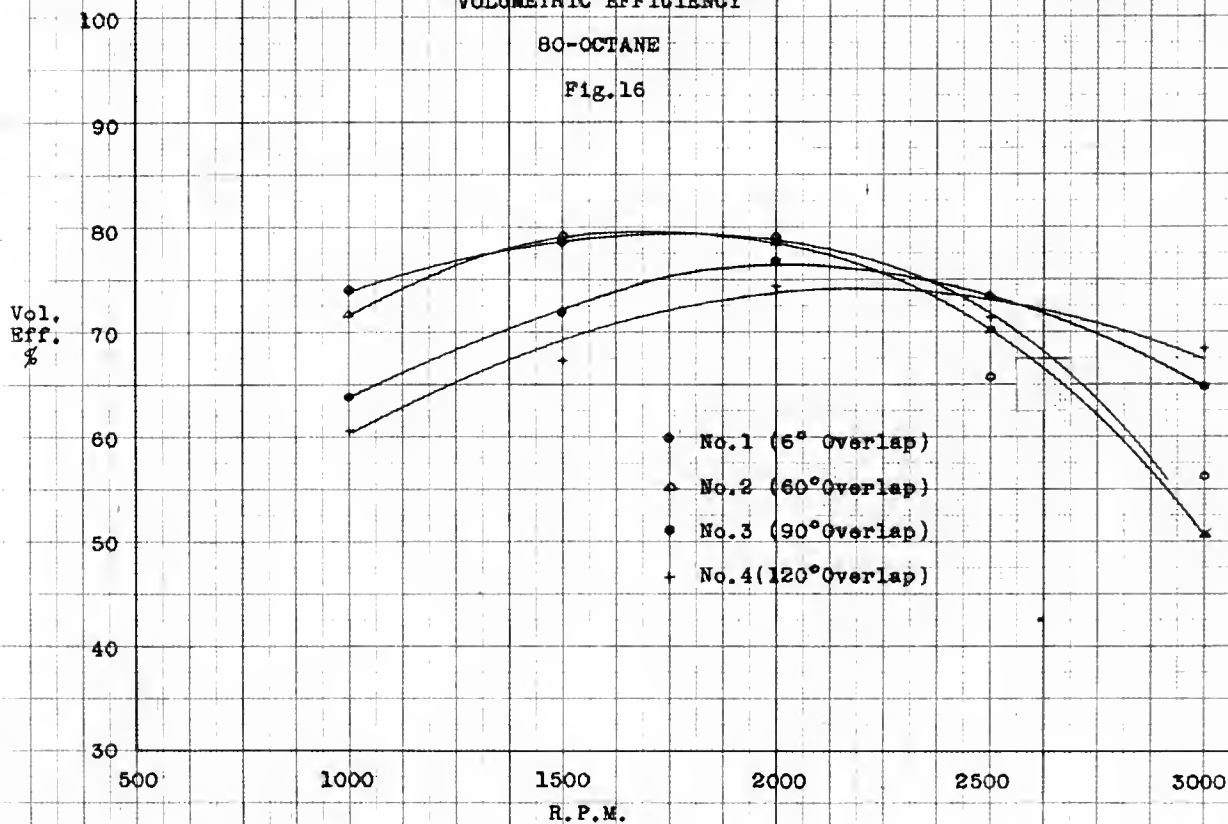


TABLE I

RUN	RPM	B.L.	Shaft Number Overlap	Compression Ratio	Spark Advance	1 6°	18° BTC	Oil Temperature										140° F							
								F.L.	P ₁	P _e	ORF.	AIR CONS.	FUEL CONS.	R	ROTO.	T _b	ΔP	P _b	IHP	IMEP	ISFC				
																						Jacket Temperature		212° F	
																						Inlet Temperature		140° F	
Fuel-Air Ratio .08																									
1	1000	14.25	-5.15	22.98	30.00	.515		.00675	80 Octane	.000540	1	8.0	77	1.5	52.33	19.4	3.88	82.3	.502						
2	1500	15.4	-6.45	24.73	30.00	.515		.01138		.000910	1	10.6	77	4.1	50.98	21.85	6.56	92.7	.500						
3	2000	16.6	-7.25	29.98	30.00	.515		.01890		.001515	1	14.3	77	12.0	48.13	23.85	9.54	101.2	.572						
4	2500	19.05	-8.05	37.23	30.00	.725		.02435		.001948	2	9.1	77	4.95	48.23	27.1	13.55	115.0	.517						
5	3000	19.3	-9.1	47.23	30.00	.725		.03170		.002540	2	10.78	77	7.45	54.43	28.4	17.04	120.5	.537						
6	2000	19.95	-6.9	30.43	30.00	.515		.01767		.001412	1	13.7	72	10.35	48.28	26.85	10.74	114.0	.473						
7	2000	16.85	-6.0	26.43	24.00	.515		.01515		.001212	1	12.55	72	7.2	49.23	22.85	9.14	97.0	.478						
8	2000	13.2	-5.75	22.03	18.00	.515		.01338		.001070	1	11.6	72	5.75	49.68	18.95	7.58	80.4	.508						
9	2000	12.9	-5.3	20.68	12.00	.515		.01198		.000958	1	10.9	72	4.6	49.93	18.2	7.28	77.2	.474						
10	1100	7.7	-3.8	50.98	30.00	.515		Di-iso-butylene										41.4	175.8	.602					
11	1500	11.8	-4.9	54.28	30.00	.515		.01900		.001520	1	14.8		9.15	63.08		9.1	175.8							
12	2000	10.6	-6.1	58.18	30.00	.725		.02710		.002170	1	18.6		19.5	59.93	46.6	13.98	198.0	.560						
13	2500	-	-	70.00	30.00	.725		.03580		.002860	2	12.0		8.0	64.48	46.6	18.62	198.0	.552						
								Incipient	Detonation			Not	Reached												
14	2000	36.2	-6.6	43.95	30.00	.515		.02800		.002240	1	19.0	77	23.4	54.01	42.8	17.13	182.0	.471						
15	2000	35.2	-6.0	43.9	24.00	.515		.02665		.002130	1	18.4	77	19.7	57.70	41.2	16.50	175.0	.465						
16	2000	35.5	-5.5	43.6	18.00	.515		.02610		.002085	1	18.1	77	19.0	57.50	41.0	16.40	174.0	.458						
17	2000	33.7	-4.9	41.0	12.00	.515		.02480		.001980	1	17.55	77	17.0	58.30	38.6	15.44	163.8	.462						
18	2000	33.3	-5.0	40.8	8.60	.515		.02450		.001960	1	17.5	77	17.2	57.80	38.3	15.31	162.4	.462						

TABLE II

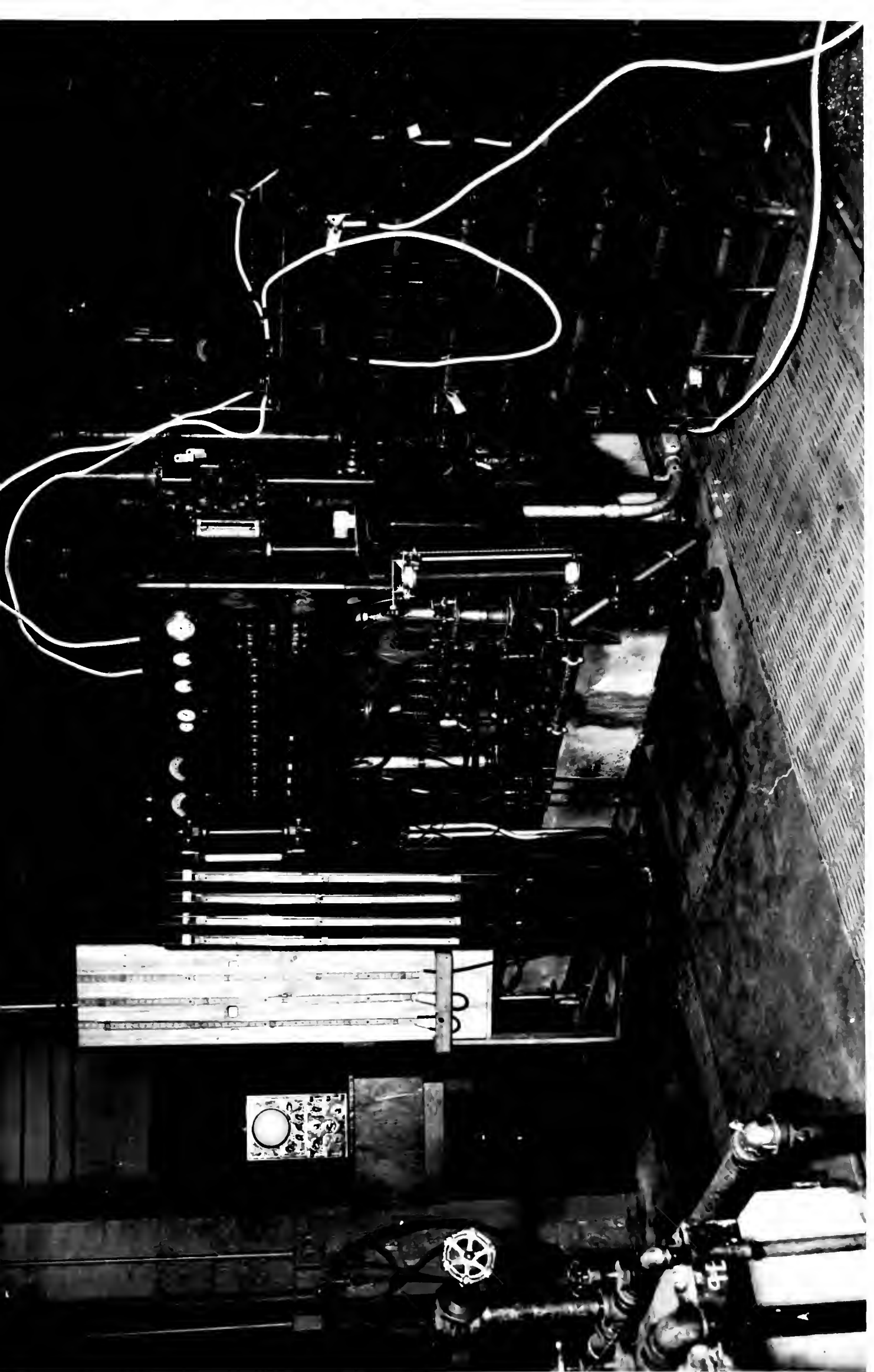
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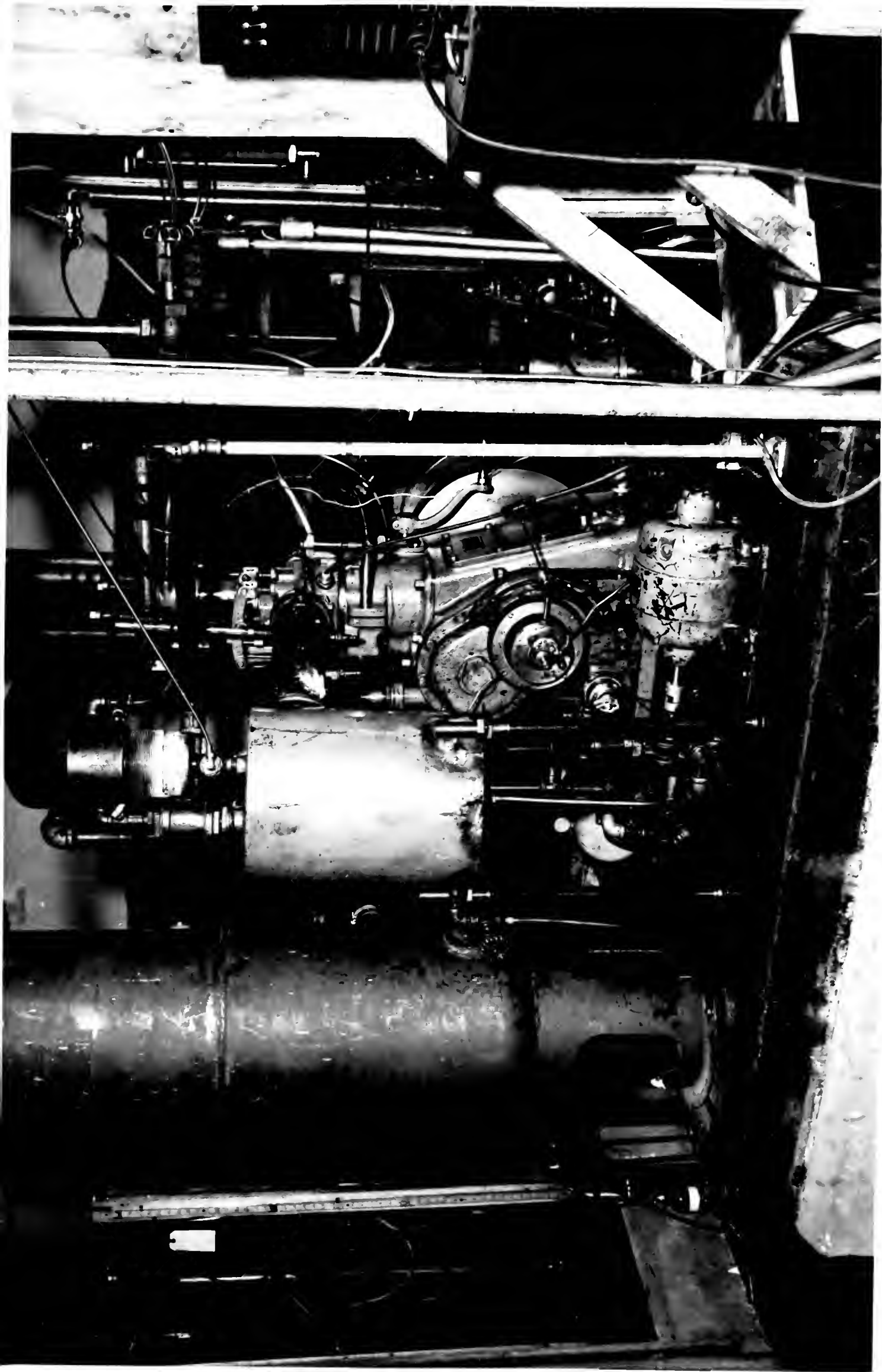
TABLE III

RUN	RPM	B.L.	Shaft Number			F.L.	P _i	P _e	ORF.	AIR CONS.	FUEL CONS.	R	ROTO.	T _b	Δ P	P _b	B.L. +F.L.	IHP	IMEP	ISFC
			Overlap	Compression Ratio	Spark Advance															
			3																	
			90°																	
			7																	
			18° BTC																	
39	1000	14.3	-4.2	25.77	30.00	.515	.00653	80 Octane	.000522	1	8.0	75	1.0	68.02	18.5	3.75	78.5		.501	
40	1500	19.8	-4.9	28.52	30.00	.515	.01228		.000980	1	11.2	75	3.65	66.37	24.7	7.41	105.0		.476	
41	2000	21.6	-6.5	30.77	30.00	.725	.01880		.001510	2	7.8	75	2.2	64.52	28.1	11.25	119.4		.482	
42	2500	27.3	-7.3	38.42	30.00	.725	.02810		.002250	2	9.9	75	5.2	60.97	34.6	17.3	147.0		.468	
43	3000	31.3	-8.6	51.2	30.00	.725	.03960		.003170	2	12.6	75	11.2	55.62	40.4	24.3	171.8		.469	
44	2000	21.5	-6.5	30.77	30.00	.725	.01880		.001510	2	7.8	75	2.2	64.52	28.0	11.2	119.0		.486	
45	2000	24.5	-5.8	30.92	24.00	.515	.02080		.001660	1	15.1	75	11.0	62.90	30.3	12.12	128.8		.492	
46	2000	25.7	-5.0	31.42	18.00	.515	.02190		.001750	1	15.7	75	12.8	60.17	30.7	12.3	130.4		.512	
47	2000	27.6	-4.4	32.42	12.00	.725	.02290		.001830	1	16.0	75	3.25	64.47	32.0	12.8	135.9		.514	
48	2000	28.2	-4.1	33.02	9.20	.725	.02340		.001870	1	16.4	75	3.40	63.42	32.3	12.93	137.2		.521	
49	1000	42.4	-3.7	50.3	30.00	.515	.02020	Di-iso-butylene	.001620	1	15.5	75	10.1	64.80	46.1	9.22	196.0		.632	
50	1500	44.1	-4.8	51.5	30.00	.725	.02920		.002340	2	10.6	75	5.6	61.10	48.9	14.7	207.0		.573	
51	2000	39.6	-6.0	52.82	30.00	.725	.03650		.002920	2	12.3	75	8.2	65.05	45.6	18.25	193.5		.577	
52	2500	36.4	-7.1	56.3	30.00	.725	.04260		.003400	2	13.5	75	11.8	61.2	43.5	21.8	184.6		.561	
53	3000	-	-	70.00	30.00	.725	Incipient	Detonation	Not Reached											
54	2000	39.6	-6.0	52.3	30.00	.515	.03650		.002920	2	12.3	75	8.2	65.05	45.6	18.25	193.5		.577	
55	2000	41.2	-4.9	52.0	24.00	.515	.03660		.002930	2	12.2	75	8.35	64.2	46.1	18.42	196.0		.572	
56	2000	44.0	-4.5	51.0	18.00	.515	.03910		.003130	2	12.7	75	9.65	63.2	48.5	19.4	206.0		.612	
57	2000	45.6	-4.1	49.0	12.00	.515	.04020		.003220	2	12.9	75	10.4	62.3	49.7	19.9	211.0		.597	
58	2000	46.1	-4.0	48.5	11.00	.515	.04080		.003270	2	13.1	75	10.8	61.95	50.1	20.05	212.5		.587	

TABLE IV

RUN	RPM	B.L.	F.L.	Shaft Number			Pe	Pi	ORF.	AIR CONS.	FUEL CONS.	R	ROTO.	Tb	ΔP	Pb	B.L. +F.L.	IHP	IMEP	ISFC	Oil Temperature			
				Overlap	120°	4															140° F	212° F	140° F	Fuel-Air Ratio
				Compression Ratio	7	180 BTC																		
				Spark Advance																				.08
60	1000	15.5	-4.1	28.55	30.00	.515	.00689	80 Octane	1	6.1	70	1.15	63.75	19.60	3.92	83.2	.407							
61	1500	18.6	-5.4	29.35	30.00	.515	.01180	.000935	1	10.7	70	3.50	62.15	24.00	7.2	101.9	.468							
62	2000	22.8	-6.4	31.55	30.00	.515	.01870	.001498	1	14.2	70	9.35	60.00	29.2	11.68	124.0	.462							
63	2500	27.9	-7.6	38.55	30.00	.515	.02750	.002200	1	18.2	70	21.25	56.80	35.5	17.75	150.8	.446							
64	3000	33.6	-8.4	50.85	30.00	.725	.04160	.003330	2	13.0	70	12.60	54.65	42.0	25.24	178.2	.475							
65	2000	22.8	-6.2	31.50	30.00	.515	.01870	.001500	1	14.2	70	9.35	60.00	29.0	11.6	123.0	.466							
66	2000	24.4	-5.6	30.00	24.00	.515	.02030	.001625	1	15.0	70	9.90	65.65	30.0	12.0	127.2	.488							
67	2000	24.5	-5.1	31.25	18.00	.515	.02280	.001820	1	16.1	70	12.75	64.90	29.6	11.84	125.5	.553							
68	2000	26.3	-4.4	33.05	12.00	.515	.02480	.001970	1	16.9	70	15.05	64.20	30.7	12.28	130.2	.579							
69	2000	30.8	-3.8	34.35	8.60	.515	.02600	.002080	1	17.5	70	17.0	63.35	34.6	13.84	146.9	.541							
70	1100	51.9	-4.0	50.86	30.00	.515	.02565	Di-iso-butylene	2	9.7	75	16.55	63.71	55.9	12.30	237.0	.600							
71	1500	40.2	-5.4	51.00	30.00	.515	.02930	.002350	2	10.6	78	22.20	62.51	45.6	13.67	193.5	.619							
72	1700	42.8	-5.1	51.21	30.00	.515	.03440	.002750	2	11.7	78	31.3	60.81	47.9	16.30	203.0	.607							
73	2100	55.2	-6.0	56.0	30.00	.725	.04200	.003380	2	13.4	75	11.05	63.65	61.2	25.67	259.5	.473							
74	2500	-	-	70.00	30.00	.725	Incipient	Detonation	Not Reached															
75	2000	37.8	-6.1	55.6	30.00	.725	.04180	.003350	2	13.3	78	11.03	63.60	43.9	17.56	186.3	.687							
76	2000	40.3	-5.1	53.1	24.00	.725	.04060	.003250	2	13.0	78	10.55	63.20	45.4	18.18	192.9	.644							
77	2000	40.1	-4.5	51.5	18.00	.725	.03970	.003180	2	12.8	78	9.80	64.60	44.6	17.80	189.1	.643							
78	2000	38.9	-4.4	50.3	12.00	.725	.03810	.003050	2	12.5	78	9.00	65.00	43.3	17.33	183.8	.632							





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